The CALICE Test Beam Programme

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Abstract. A very challenging test beam programme is being undertaken by the CALICE collaboration as part of a major R&D directed towards the design of an ILC calorimeter. This design has to be optimized for both performance and cost, where particle flow (PFA) calorimetry and software compensation are the main aim of the studies. This paper will concentrate on describing the experimental set-ups for the 2006, 2007 and 2008 test beams that have been carried out by the CALICE collaboration at CERN and FNAL.

1. Introduction
The CALICE collaboration is involved in a major programme of R&D into calorimetry for the International Linear Collider (ILC)[1]. The aim of the project is to compare the performance of different technologies for electromagnetic and hadronic calorimeters in terms of ILC requirements in a common framework. The main direction of the collaboration R&D is to study particle flow (PFA) calorimetry[2], software compensation and individual particle reconstruction, and therefore the studies are concentrating on fine granularity calorimeters with a high degree of longitudinal segmentation. These studies include comparison of test beam data with simulation models to measure their degree of agreement, the technical issues of building a detector optimized for PFA calorimetry, and development of algorithms for software compensation and particle flow reconstruction. For this purpose, a very intense test beam programme is being undertaken for extensive tests of calorimeter prototypes.

2. The 2006 test beam set-up at CERN
In August and October 2006, the CALICE Silicon Tungsten Electromagnetic calorimeter (SiW-ECAL)[3] and Analogue Hadronic calorimeter (AHCAL)[4] prototypes were tested in the H6B[5] experimental area at the CERN SPS. A detailed description of the SiW-ECAL prototype is given in reference [3]. It consists of 3 sets of 10 layers of tungsten of 1.4, 2.8 and 4.2 mm thickness respectively, for a total of 24 radiation lengths at normal incidence. Thirty layers of silicon PIN diode pads interleaved between the tungsten plates are used to sample the shower development. Each silicon pad is 1x1cm² and the sensors are made on 4 inch wafers in units of 6x6 pads. The layers consist of a 3x2 array of wafers, corresponding to 18 pads horizontally and 12 pads vertically, leading to a total of 6480 pads for the whole ECAL prototype (see figure 1). The readout of the SiW-ECAL is through a custom on-detector ASIC and VME readout boards[3]. The AHCAL prototype[4] is a sampling calorimeter with 38 layers of steel absorber sheets, instrumented with scintillator tiles which are read out using SiPMs[6]. The tiles are of varying size,
with the highest granularity central region using 3x3cm$^2$ tiles, increasing to 12x12cm$^2$ for the outmost tiles, for a total of number of ~8,000 channels (see figure 2). The readout from the SiPM is through a custom on-detector board and the AHCAL uses the same VME readout boards as the SiW-ECAL. The total interaction length of the AHCAL prototype is 4.5\lambda.

The hadronic calorimeter is complemented by a Tail Catcher and Muon Tracker (TCMT) detector[7], consisting of 96cm of iron instrumented with 16 layers of 0.5x5cm$^2$ scintillator strips, which tags the shower leakage and detect muons (see figure 3). It has a total of around 300 channels and the scintillator strips use the same SiPM readout and have the same downstream readout electronics as the AHCAL.

**Figure 1.** The CALICE SiW-ECAL prototype.

The beam line installation at CERN included locally provided beam detectors (multi wired proportional chambers – MWPC) and custom made scintillation detectors for the experimental trigger. A sketch of the experimental setup is shown in figure 4.

**Figure 2.** One scintillator layer of the CALICE AHCAL prototype

**Figure 3.** The CALICE TCMT prototype.
All the prototypes have been tested on the CERN SPS beam line during two separate test beam periods, in August and October 2006. The three prototypes were installed in the H6B experimental line, as detailed in figure 5.

In the August period, data have been taken with the SiW-ECAL and AHCAL, and also with only the SiW-ECAL on the beam line. Electron and pion beams have been used, with energies between 6 and 50 GeV for electrons and 30 to 80 GeV for pions. Since the SiW-ECAL was mounted on a platform that allowed it to be rotated, data have been taken for 4 different SiW-ECAL angles in the ECAL+AHCAL period (0°, 10°, 20°, 30°), and for 5 different angles in the ECAL alone period (0°, 10°, 20°, 30°, 45°).

A total of ~11 million triggers were collected in the first beam period only. In October, the full system consisting of SiW-ECAL, AHCAL and TCMT was exposed to the SPS beam, using e⁺ beams from 6 to 45 GeV and π± beams from 6 to 60 GeV. A total of ~6 million triggers were collected. For calibration, an additional 70 million muon events were recorded in both beam periods, for a total of ~6 TB of data (beam+calibration) events collected on disk. A summary of the total data recorded at the
2006 test beam is shown in figure 6. The analysis of both the electron and pion data in the SiW-ECAL and AHCAL is well under way and is detailed in various contributions in these proceedings (see [8-12]).

3. The 2007 test beam at CERN
Between June and August 2007 the Calice collaboration has successfully commissioned and operated the full chain of calorimeter prototypes in the H6B experimental area at the CERN SPS (figure 7).

![Figure 7](image-url) Figure 7. The installation of the CALICE SiW-ECAL, AHCAL and TCMT at the 2007 CERN test beam.

In 2007, the ECAL was equipped with 30 sensitive layers of silicon pads, corresponding to a total of 54 PCBs. The total number of readout channels was 9072, corresponding to 216 channels/PCB in the central part of the detector and 108 channels/PCB in the bottom part. A total of 38 fully commissioned modules of the AHCAL were installed on the beam line; 30 modules with fine granularity (216 scintillator tiles) and 8 modules with coarse granularity (141 tiles) were present. Each tile is readout by a silicon photo-multiplier (SiPM), for a total of 7608 readout channels. The TCMT was completely installed with all 16 active layers fully instrumented and a total of 320 readout channels.

The trigger to the experiment is provided by the coincidence of two 10x10cm² scintillator plates with photo-multiplier readout. In addition a coincidence with a muon wall downstream of the detector may be used either for muon rejection or as a muon trigger during calibration. The analogue readout of an additional 20x20cm² scintillator plate serves as veto for events with double particles or showers initiated in the material upstream of the detector. In order to tag the halo of the beam, an additional 100x100cm² scintillator with a 20x20cm² hole has been employed as an outer veto. All triggers are digitized and recorded event by event by the VME-based data acquisition (DAQ), and can be used offline for data selection. A threshold Cherenkov counter filled with helium gas has been used to discriminate electrons from pions, in the range 6-20 GeV. The same detector has also been used with
nitrogen gas in order to discriminate pions and protons in the range 30-80 GeV. The gas pressure in the 11m long Cherenkov vessel needs to be adjusted depending on the beam energy. With optimal settings, efficiencies of 90% are obtained, going to 30 % with increasing energy. The discriminated Cherenkov signal is recorded as a trigger bit. For particle tracking, three sets of delay multi-wire proportional chambers provided by CERN have been included in the CALICE DAQ. Three pairs of x and y planes with two wires each are read out for each event by a TDC implemented in the DAQ. The spatial resolution of the tracking system is better than 200μm.

The system, with more than 16000 channels and an acquisition rate capability of 120 Hz (see figure 8), is a compact HEP experiment in itself.

![Data acquisition rate](image)

**Figure 8.** Data acquisition rate for the 2007 CALICE test beam at CERN. The average acquisition rate (black line) is ~50 Hz.

The performance of all beam-line detectors as well as that of the 3 calorimeter prototypes has been monitored online during data taking. A special fast analysis tool has been developed to access in real time the relevant beam and detector qualities. Several checks have been possible to monitor the response of the calorimeters at different energies. The preliminary response for the SiW-ECAL and AHCAL (with no calibration) can bee seen in figure 9 and 10.

The programme for the test beam has been very intense and has been completely fulfilled at the end of the 7 weeks of data taking. The collaboration has collected more than 200 million events (see figure 11 and 12), completing the muon calibration of all components, the electromagnetic program of both ECAL and AHCAL and hadronic program for the combined detector at four different incident angles of the beam. Both ‘minus’ (e/π−) and ‘plus’ (e+/p+/proton) beam events have been recorded. A full scan of the calorimeters’ front faces has been performed, as detailed in figure 13.

An important part of this year’s test beam has been the irradiation of a test SiW-ECAL PCB with embedded electronics, to evaluate a second generation prototype of electronics for the ILC. The irradiation has been performed using 70 GeV and 90 GeV electron beams, and doing a complete position scan of the four chips present in the test board, as shown in figure 14. The test PCB has been inserted in the SiW-ECAL structure at the point of the shower maximum.

The most ambitious part of the test beam programme has been the rotation of the SiW-ECAL and AHCAL prototypes, with subsequent re-staggering of the active parts of the calorimeters. The success of this part of the programme has been possible thanks to the movable stage on which the SiW-ECAL and AHCAL have been installed.
Figure 9. Response of the CALICE SiW-ECAL to electron beams, obtained analysing the data taken at the 2007 CERN test beam using the on-line monitoring programme.

Figure 10. Response of the CALICE AHCAL to pion beams, obtained analysing the data taken at the 2007 CERN test beam using the on-line monitoring programme.

This 16 tonnes structure, designed and built at Desy, allowed for the X and Y movement of all the calorimeters. Moreover, the SiW-ECAL and AHCAL have been mounted on a steel platform that could be rotated to a maximum of 30 degrees with respect to the direction of the beam. Data have been collected with the SiW-ECAL and AHCAL rotated by 10°, 20° and 30° with respect to the normal beam incidence direction (see figure 15).

Figure 11. Total integrated luminosity collected at the 2007 CALICE test beam at CERN.

Figure 12. Data types collected during the 2007 CALICE test beam at CERN: 62% of the collected data are e/π/p interactions in the calorimeters.

All data collected during the test beam where immediately processed and reconstructed using the Grid tools. The recorded runs were available from the Desy dcache to the whole collaboration within hours of being collected at CERN.

4. The 2008 test beam at FNAL

In April 2008, the full chain of calorimeter prototypes has been installed on the MTBF test beam line[13] at Fermi National Accelerator Laboratory (FNAL) in Batavia (IL, USA), see figure 16. The prototypes will be tested using electron and pion beams from 6 to 60 GeV, in order to get a data sample that could later be compared to the one collected at CERN. A full programme of integration of different calorimeter prototypes, like the SiW-ECAL with a Digital HCAL (DHCAL) prototype[14] or
a Scintillator ECAL prototype[15] with the AHCAL, will be performed, in order to optimize different choices of electromagnetic and hadronic calorimeters for the ILC.

**Figure 13.** Summary of the position scanning on the front face of the SiW-ECAL performed at the 2007 CALICE test beam at CERN.

**Figure 14.** Sketch of the scanning of the SiW-ECAL PCB with embedded electronics performed at the 2007 CALICE test beam at CERN.

5. Conclusions

During 2006 and 2007 the CALICE collaboration has performed extremely successful test beams at the H6B experimental area at CERN. More than 260 million events have been collected during both tests and all the data are available on the Grid.

**Figure 15.** Set-up of the SiW-ECAL and AHCAL after the 30° rotation of the movable platform.

The analysis of the data is well under way and preliminary results have been shown during this conference and are summarized in these proceedings. The next phase of beam tests of the CALICE calorimeter prototypes is started in April 2008, when the detectors have been installed at the MTBF
test beam area at FNAL. One of the aims of this year’s tests will be to expose different combination of calorimeter prototypes to electron and pion beams (e.g. SiW-ECAL with DHCAL or Sci-ECAL with AHCAL), in order to optimize the choice of calorimeters for a future Linear Collider detector.

Figure 16. Set-up of the SiW-ECAL and AHCAL at the MTBF beam line at FNAL (April 2008).

6. References
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